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1. Your reference: RJ/LT/N15339

2. Patent application number *(The Patent Office will fill this part)*: 0404419.4 — 27 FEB 2004

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Intelligent Textiles Limited
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Egham, Surrey TW20 0JZ

Patents ADP number *(if you know it)*: 8819146001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

Electrical Components and Circuits Constructed as Textiles

5. Name of your agent *(if you have one)*: Williams Powell

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Morley House, 26-30 Holborn Viaduct
London
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Patents ADP number *(if you know it)*: 5830310001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

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12. Name and daytime telephone number of person to contact in the United Kingdom — Mr Lee Anderson 020 7936 3300

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ELECTRICAL COMPONENTS AND CIRCUITS CONSTRUCTED AS TEXTILES

The present invention relates to the provision and incorporation of electrical components with a textile.

The applicants' previous patent application PCT/GB01/01518 discloses several embodiments of localised yarn structures in woven, knitted and non-woven textiles that incorporate both electrically conductive and electrically insulative yarns for the purposes of constructing switches and pressure sensors therefrom.

These structures and arrangements of yarns are principally concerned with controlling the amount of electrical contact that occurs between two or more electrically conductive yarns, or analogous elongate electrical conductors, that cross over one another within the plane of the textile. Techniques are described in PCT/GB01/01518 whereby the aforementioned electrically conductive yarns can be affixed in permanent electrical contact with one another, or permanently separated by insulative yarns and/or an air gap such that no electrical contact takes place between them.

Certain structures and manufacturing parameters allow for the latter, separated, case to become extended in function, such that the conductive yarns remain electrically separate until a mechanical force is exerted upon the textile structure in a direction substantially perpendicular to the plane of the fabric. Under this condition, one or other of the separated electrically conductive yarns can be made to traverse the separating air gap and/or push aside the insulative elements and thus be brought into electrical contact with the other conductive yarn or yarns. This structure thus constitutes a mechanically actuated electrical switch, sensitive to force or pressure.

Preferably, the types of crossover structures used from patent PCT/GB01/01518 are those pertaining to woven fabrics that incorporate non-composite conductive yarns; that is, monofilament yarns or multifilament yarns comprising a plurality of similar monofilaments, that exhibit a uniformly conductive outer surface. This excludes those composite yarns described in PCT/GB01/01518 that comprise both conductive and insulative elements, but includes the majority of commercially available conductive yarns, which tend to be composed of pure metallic conductive filaments or filaments that are uniformly coated with a metallic or non-metallic (usually carbon) conductive material.

The preferred separation technique for use with non-composite conductive yarns in a woven textile is the use of a weave structure with floats, a term applied to a portion of weft yarn that passes over or under more than one warp yarn or vice-versa, as described in PCT/GB01/01518.

To achieve separation of the two conductive yarns at a crossover, typically, the weft conductive yarn is floated over the warp conductive yarn and one or more insulating warp yarns to either side, as is shown in Figure 1. As a result, the two conductive yarns share little or no physical contact area, as shown in the cross-sectional view, longitudinal to the weft, of Figure 2(a). If the conductive warp yarn is of smaller diameter than the surrounding insulating warp yarns, the physical separation of the two conductive yarns can be effected, as shown in Figure 2(b).

Conversely, if it is desired that the two or more conductive yarns make permanent electrical contact at their point of crossing over one another, a plain weave structure is used, as shown in Figure 2(c). This weave structure guarantees a large contact area between the respective surfaces of the conductive yarns and is particularly efficacious when applied to multifilament yarns, which exhibit a conformable cross-sectional profile.

The majority of prior art on textile resistive elements is concerned with electrical heating. Much of this prior art, for instance US20010002669A1, US6452138B1, GB657729 and GB428036, is in turn concerned with the creation of a suitably flexible non-textile heating element which is then incorporated in or appended to a textile substrate. In some cases, for instance US6172344, US4764665 and US4149066, the heating element is formed as an electrically conductive coating or surface upon a textile substrate. These techniques suffer the disadvantages of complex, many-stage production processes and deterioration in use due to the heating element or material becoming separated from its textile substrate.

The present invention seeks to provide electrical components with a textile, preferably a woven textile.

According to an aspect of the present invention, there is provided an electrical component woven in a textile substrate. Advantageously, the component is produced during the process of weaving of the textile, by use of one or more of conductive, resistive and insulative elements.

Preferably, at least two separated bus-bars are woven into the textile.

In the preferred embodiment, at least one resistive element is provided in the textile, most preferably provided by a plurality of resistive elements connected to one another in series and/or in parallel. Advantageously, the resistive elements are permanently coupled to one another in an operational state of the device.

Another aspect of the present invention provides the use of cross-over weave structures to allow two or more mutually separated bus bars to be incorporated into a textile during the weaving process.

According to another aspect of the present invention, there is provided an electrical circuit or structure within a textile including a plurality of one or more of conductive, resistive and insulative elements which are pressure actuated into contact, which are permanently unconnected and/or which a fully conductive. The elements are preferably incorporated into the weft and warp fibres of the textile.

The present invention is concerned with the utilisation of these three types of crossover structure, namely permanently connected, permanently unconnected and pressure actuated switch, to construct a wide variety of electrical components in the form of conventionally manufactured textiles.

This "toolbox" of techniques thus comprises: the aforementioned joining and separating weave structures; the row and column arrangement of conductors that results from interspersing conductive yarns amongst insulative yarns in the warp and weft of a woven textile; and the variety of conductivities exhibited by commercially available conductive yarns.

Embodiments of the present invention are described below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows in schematic form a woven piece of fabric, showing conductive and insulative yarns, with weft floats at crossover points between conductors;

Figures 2a to 2c shows in cross-section weaving conductive yarns with weft floats or plain weave at crossovers to control contact area;

Figure 3 is a legend for the other Figures;

Figure 4 shows a simple resistive element;

Figure 5 shows a parallel resistive element;

Figure 6 shows a series resistive element with serpentine structure according to an embodiment of the present invention;

Figure 7 shows a series resistive element with a spiral structure, according to an embodiment of the invention; and

Figure 8 shows a parallel interlaced resistive element according to an embodiment of the present invention.

The following description details how the techniques taught herein are used in combination to construct electrical components. A standard notation has been adopted for the accompanying drawings, the legend for which is illustrated in Figure 3.

According to this legend, three symbols are employed to represent the three types of crossover structure that are available. The first represents a crossover point that is a mechanical switch, using weave structures described in patent PCT/GB01/01518. The second open circle symbol represents a crossover at which the two or more conductive yarns are permanently separated, using a warp or weft float structure, also described in patent PCT/GB01/01518. The third filled circle symbol represents a crossover point at which the conductive yarns are permanently connected, through the use of a plain weave structure.

Further, two broad classifications of conductive yarn are represented by the use of heavy or thin lines within the diagrams. Heavy lines represent fully conductive yarns, which are typically metallic in nature. For the purposes of the following analyses, these yarns are assumed to exhibit negligible resistivity, although in practice they may typically exhibit linear resistivities of up to around 10 ohms/cm, and acceptably exhibit linear resistivities of up to 100 ohms/cm.

Thin lines within the diagrams represent resistive yarns, more specifically, conductive yarns which exhibit greater linear resistivity than the fully conductive yarns. These yarns are predominantly based upon carbon as an electrically conductive medium, and depending upon their thickness typically exhibit linear resistivities of between 1,000

and 10,000 ohms/cm. It is also envisaged that these resistive yarns might use semiconductor materials as a resistive medium.

These resistive yarns are distinct again from the insulative yarns that comprise the remainder of the textile. The insulative yarns can be taken from the majority of the range of commercially available yarns, including both natural fibre yarns such as wool, cotton and silk, or man-made fibres such as nylon and polyester.

The insulative yarns are omitted from the drawings for the purposes of clarity, although it is implicit to the designs that each conductive yarn is separated from any other adjacent and parallel conductive yarns by at least one interposed, parallel insulative yarn. Where this is not the case, for instance where a number of yarns are used in parallel to reduce the overall linear resistivity of that length of conductor, the multiplicity of yarns is treated as a single conductive yarn for the purposes of these analyses and descriptions. That is, either of the conductive yarn types described or illustrated within this application may in practice comprise a single yarn or a multiplicity of yarns.

To a certain extent, the drawings are schematic and may be reorganised topologically, akin to a conventional electrical schematic diagram. However, certain dimensions within some of the designs are not topological equivalents, and the variation of these distances or arrangements will effect change upon the function of the designs. These important dimensions, where they exist, are indicated upon the drawings and in the analyses.

The remainder of the dimensions are arbitrary, certainly when these dimensions concern fully conductive yarns, whose resistivity can be considered negligible. This factor enables greater freedom of design as regards the physical layout of a component or circuit when embodied as a piece of textile.

Indeed, the variable topology of the structures allows them to be positioned arbitrarily within a piece of textile, allows many distinct structures to be incorporated within a single piece of textile and allows interconnection between these distinct structures. For example, a single piece of textile might be designed to incorporate a number of resistive elements, transducer elements and switch elements in arbitrarily determined positions, plus the signal and power interconnections and buses between them. A simpler, but very useful advantage of the variable topology is that any connection points that are required between the textile and some external electrical device can also be arbitrarily positioned, usually most usefully towards one edge of the textile.

Resistive Elements

Perhaps the most basic electrical component that can be embodied as a woven textile is the resistor. A resistor will also constitute an impedance or reactance, according to its mode of use. Envisaged applications include, but are not limited to, its use: as a resistance component within a larger circuit; as a matched impedance for either the termination of a transmission line or its use as an antenna; as a resistive heating element; as

an effector, where, for example, resistance heating or the creation of magnetic flux effects some physical change in the textile; as a sensor or transducer, where the effective resistance value varies in relation to some external influence such as strain, temperature, incident light levels or magnetic flux.

It is also envisaged in these latter cases that the resistive yarns might use some semiconductor material as a conductive medium, such that a sensing or effecting function is enhanced. For example, the use of a resistive yarn that employed Cadmium Sulphide as a conductive medium would render the yarn, or region of fabric that constitutes the resistive element, greatly sensitive to incident light levels via measurement of its resistance value.

In order for a textile resistive element to be used in most of these applications, some measure of control over the resulting resistance value is required. Consider the simplest manner in which a resistive element can be constructed within a woven textile, with some degree of control over the resultant resistance value. This is illustrated in Figure 4.

Control of the resistance value is achieved through control of the effective length of a single conductive yarn, or more correctly, a single conductive "end", which may comprise one or more distinct yarns woven in unison.

The effective length refers to the length of the electrical conduction path, through one or more conductive yarns of uniform and known linear resistivity, measured in ohms/unit length. The length of this conduction path may be controlled by the overall length of the piece of textile, or the positioning of two connectors at either extreme of the desired length of conductive yarn.

Advantageously, as in the case of Figure 4, it is possible to control the effective length of a resistive yarn between two fully conductive connector yarns, or bus-bars. The effective length of the resistive yarn is thus fixed at time of weaving, through the geometry of the warp design. In this case, and assuming that the resistance of the fully conductive bus-bars is negligible, the resultant resistance of the element is given by:

$$R_{AB} = L \times \rho$$

where, with respect to Figure 4, R_{AB} is the resultant resistance measured between points A and B, L is the effective length of the resistive yarn, or the distance between the bus-bars, and ρ is the linear resistivity of the resistive yarn, measured in ohms/unit length.

This simple arrangement suffers a number of drawbacks. Primarily, the range of linear resistivities offered by available conductive yarns is limited, which in turn limits the range of resultant resistances that realistically can be constructed. As previously discussed, available yarns are typically either metallic, all offering similarly low linear resistivities, or carbon-based, offering a relatively high linear resistivity. Achieving many intermediate resistance values can therefore demand unrealistically large or small values of L.

Additionally, many applications, such as heating elements and transducers, require the textile resistive elements to conform to certain geometries.

A partial solution to these drawbacks can be achieved through the use of multiple resistive yarns that are arranged in a parallel array as shown in Figure 5. These parallel resistive yarns can be electrically connected together at either extreme by perpendicular conductive yarns. If fully conductive yarns of negligible resistance are used to electrically connect the parallel array of yarns, as in this diagram, the fully conductive yarns constitute electrical bus-bars, and the resultant resistance of the element is given by the equation:

$$R_{AB} = (L \times \rho) / N$$

where, with respect to Figure 5, R_{AB} is the resultant resistance, L is the effective length of the resistive yarns, or the distance between the bus-bars, ρ is the linear resistivity of the resistive yarn used, measured in ohms/unit length and N is the number of parallel resistive yarns.

Structures of this nature can be seen in patents EP1201806A2 and associated family, US4538054A, RU2145984C1, RU2187907C1 and RU2155461C1.

The systems seen in this prior art suffer the general disadvantages of yielding only limited ranges of resultant resistance from given yarn resistivities, having complicated manufacturing that involves multiplicities of processes, and yielding resistive elements of limited geometry, large size and homogenous distribution of resistance.

The teachings herein address these disadvantages, by employing the techniques for connecting or not connecting conductive yarns at crossover points.

Figure 6 illustrates a means by which a textile resistive element with a very long effective length can be restructured to fit within a piece of textile of arbitrary proportions. The conductive path between points A and B is arranged in a serpentine manner, passing from one resistive yarn to another in electrical series via the staggered bus-bars that are comprised of the perpendicular fully conductive yarns at either extreme of the resistive yarns.

In Figure 6, if the fully conductive yarns that comprise the bus-bars are assumed to contribute negligible resistance to the conductive path between points A and B, and the bus-bars at one extreme of the resistive yarns are arranged to be equally spaced to those at the other extreme, according to the dimensions L and K in Figure 6, then the resultant resistance is given by the sum of the resistive yarns that comprise the effective conductive path. That is:

$$R_{AB} = (L \times \rho) + (K \times \rho) + (L \times \rho) + (K \times \rho) + \ldots$$

and so on, where, with respect to Figure 6, R_{AB} is the resultant resistance measured between points A and B, K and L are the effective lengths of the resistive yarns, [illegible]

distances between the bus-bars, and ρ is the linear resistivity of the resistive yarn, measured in ohms/unit length.

For an arbitrary number of resistive yarns, N, arranged in this manner according to Figure 6, the overall resultant resistance is given by:

$$R_{AB} = (N/2) \times ((L \times \rho) + (K \times \rho))$$

It is clear that this is an illustrative form of the structure, and that if the resistance of the bus-bars cannot be assumed to be negligible, or the effective lengths of the individual resistive yarns is not so uniform, then the overall resultant resistance can be determined by considering every component of the conductive path in turn. Each component contributes a finite resistance according to its own effective length and linear resistivity, and the overall resultant resistance is the sum of these component resistances, according to the nature of electrical resistances connected in series.

Indeed, there is no real compulsion for a generalised series resistance structure to conform to a serpentine arrangement at all, beyond convenience of annotation and design and a certain convenience of manufacture. Consider the structure of Figure 7, in which the series resistances of the effective conductive path are arranged in a spiral manner.

Note that these series structures allow greatly improved control over the geometry of resistance elements described thus far, and seen in the prior art. The serpentine structure allows a resistive element to conform to almost any arbitrary rectilinear proportions. A decrease in the dimensions K and L for a given resultant resistance can be compensated for by an increase in N, and vice-versa. Additionally, this series structure can create absolute resistances that are higher in value than the simple resistive element of Figure 4, for a given dimension L and linear resistivity ρ, unlike the parallel structures of Figure 5 and the prior art, which only allow the creation of lower resistances under the same conditions.

It is a further disadvantage of the parallel resistive structures of Figure 5 and the prior art that very low resistances, relative to those of the simple resistive element of Figure 4 for a given dimension L and linear resistivity ρ, are difficult to achieve within a controlled geometry. Achieving progressively lower resultant resistances with a parallel structure such as that of Figure 5 requires that L becomes very small and N becomes very large, and the overall geometry of the resistive element becomes ever-more tall and narrow.

The preferred embodiments disclosed herein address this drawback. Figure 8 illustrates a means by which a textile resistive element with a very high number of parallel conductive paths, each of very short length, can be structured to fit within a piece of textile of arbitrary proportions, and to an extent of arbitrary size.

The effective conductive path between points A and B is split by the bus-bars into a multitude of parallel sub-paths, each of which in turn then comprises a parallel structure of the sort seen in Figure 5.

Each bus-bar has become extended by an array of fully conductive yarns, such that its conductive path becomes comb-like in shape. The two comb-shaped bus-bars are staggered within the textile, such that the fingers of the combs become interlaced, but maintain electrical isolation from one another.

It is between these interlaced fingers that the resistive yarns are disposed. Assume there are P interlaced fingers in total, and N resistive yarns, according to Figure 8. This results in a potentially very high number of parallel conductive paths between points A and B, through the many portions of resistive yarn, yet in a very compact area and making economical use of the resistive yarns. The equivalent circuit for this structure is shown in Figure 9.

To analyse this structure, with respect to Figures 8 and 9, firstly consider a single elemental resistor of value r, which is formed by a portion of a single resistive yarn of length L. The value of this elemental resistor, r, is given by:

$$r = L \times \rho$$

where, with respect to Figure 8, L is the length of the portion of yarn and ρ is the linear resistivity of the resistive yarn, measured in ohms/unit length.

Assuming that the yarn portions are all of a similar dimension and composition, and thus that the elemental resistors are all of value r, consider now that there is a multiplicity of such elemental resistors. They are arranged, in the particular instance of Figure 8, from left to right as rows and numbering N, and also from top to bottom in columns, numbering $(P - 1)$. The number of elemental resistors of value r is thus equal to the product of these row and column numbers, such that the overall resultant resistance between points A and B, R_{AB}, is given by:

$$R_{AB} = (L \times \rho) / (N \times (P - 1))$$

Note that the overall length of the resistive element is given by $L \times (P - 1)$. Therefore, for a given overall length, if P is increased L is reduced proportionally, both of which effects serve in concert to reduce the resultant resistance. From this it can be seen that even if the ρ term is large, or the number of resistive yarns N is low, or the overall length of the resistive element is required to be very short, the resultant value R_{AB} can still be made very low by increasing the value of P and simultaneously decreasing L.

Thus, the preferred embodiments of structure disclosed herein allow a very broad range of resultant resistances to be generated within a given area and shape of textile and with a limited range of available yarn conductivities. Conversely, a resistive element of a desired resistance can be created in a wide variety of rectilinear shapes and sizes.

A similar electrical structure can be seen in the prior art of RU2155461C1, but which suffers the relative drawbacks that the bus-bars must be appended after the manufacture of the textile, and must also be cut in a further manufacturing process in order to separate the two comb-shaped bus-bars. The manufacturing process is thus greatly more

complicated in comparison with the embodiments disclosed herein, in which the use of the crossover weave structures allow the two mutually separated bus-bars to be incorporated within the process of weaving of the substrate textile. Additionally, the prior art's requirement to cut into the fabric limits the smallness and number of resistive elements that can be realistically created within a piece of textile, which in turn limits the range of resultant resistances that can be obtained.

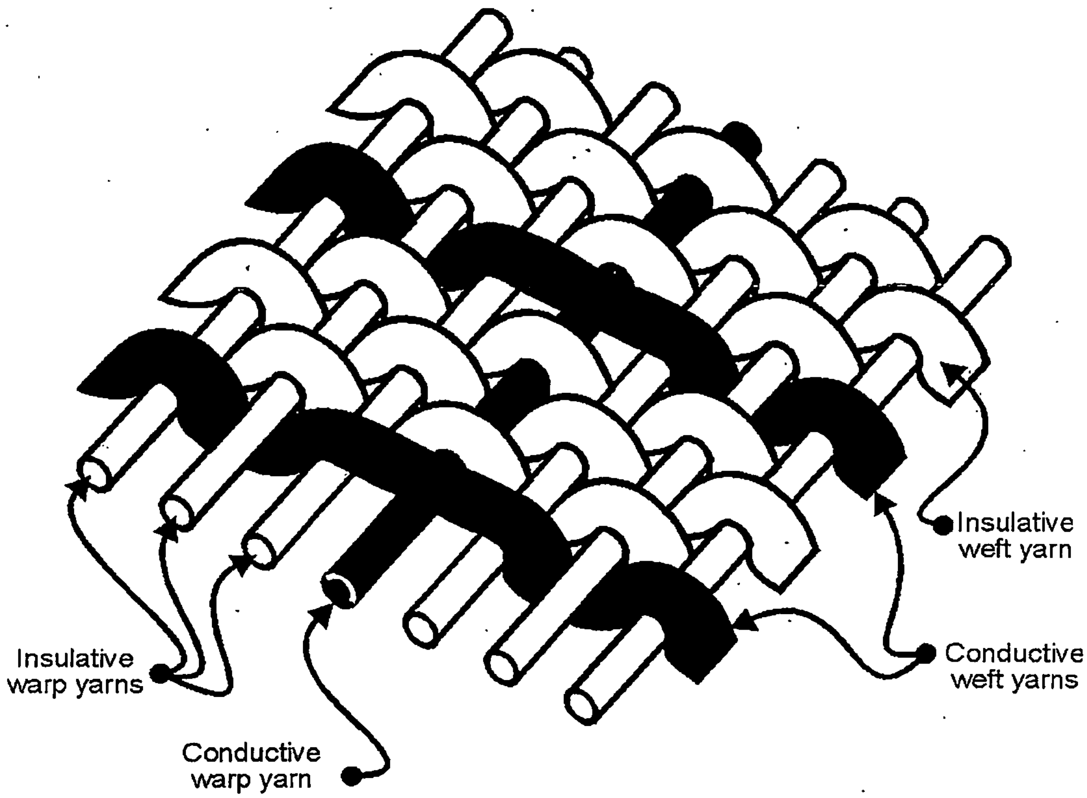
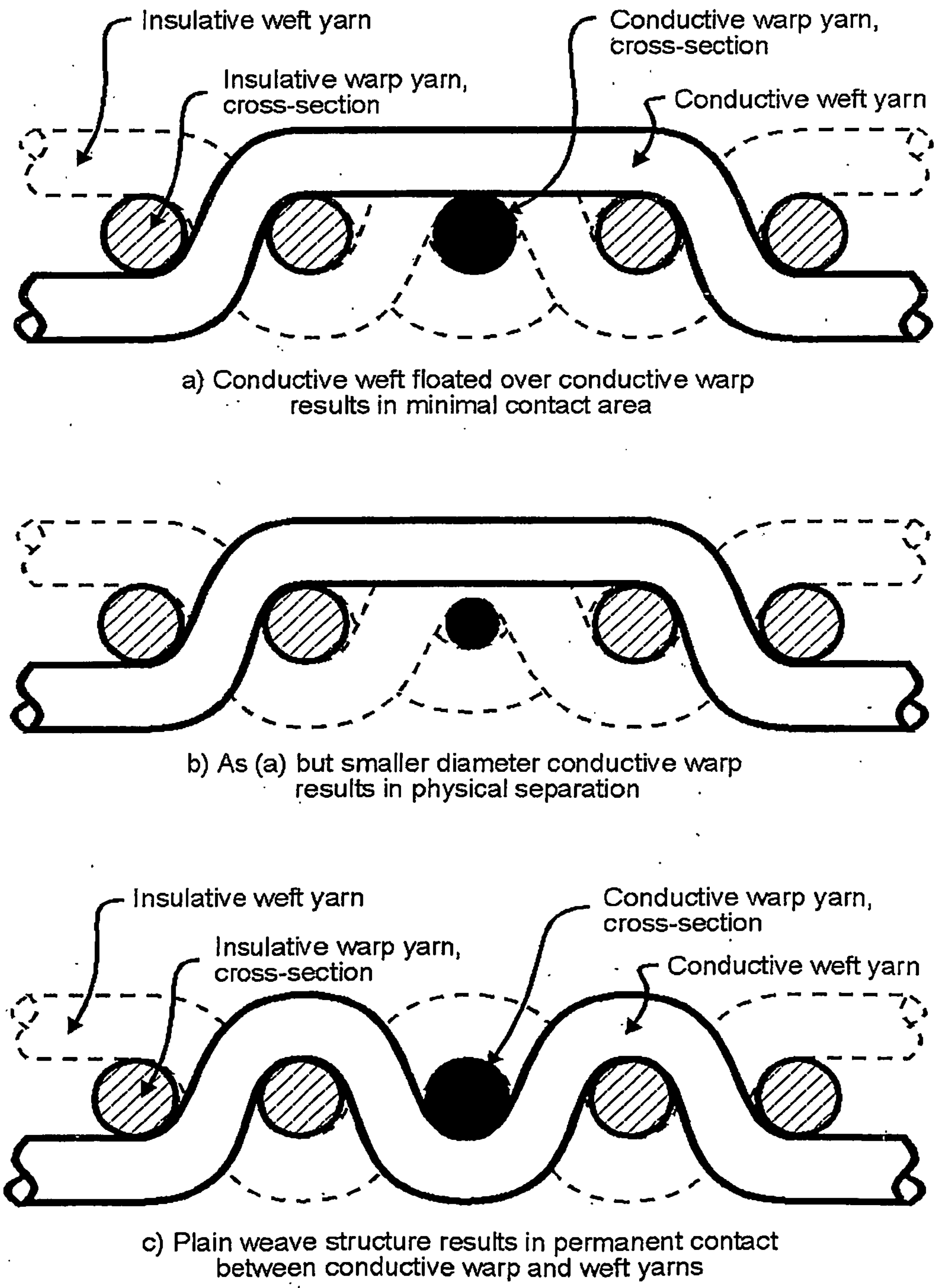


Figure 1. Woven piece of fabric, showing conductive and insulative yarns, with weft floats at crossover points between conductors

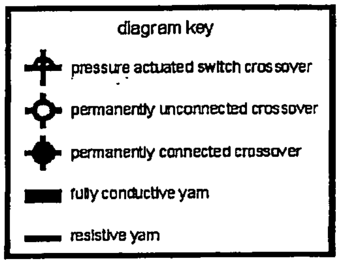


a) Conductive weft floated over conductive warp results in minimal contact area

b) As (a) but smaller diameter conductive warp results in physical separation

c) Plain weave structure results in permanent contact between conductive warp and weft yarns

Figure 2. Weaving conductive yarns with weft floats or plain weave at crossovers to control contact area, cross sectional views



N.B. only conductive yarns
shown for clarity

Figure 3. Legend for Weaving Schematics

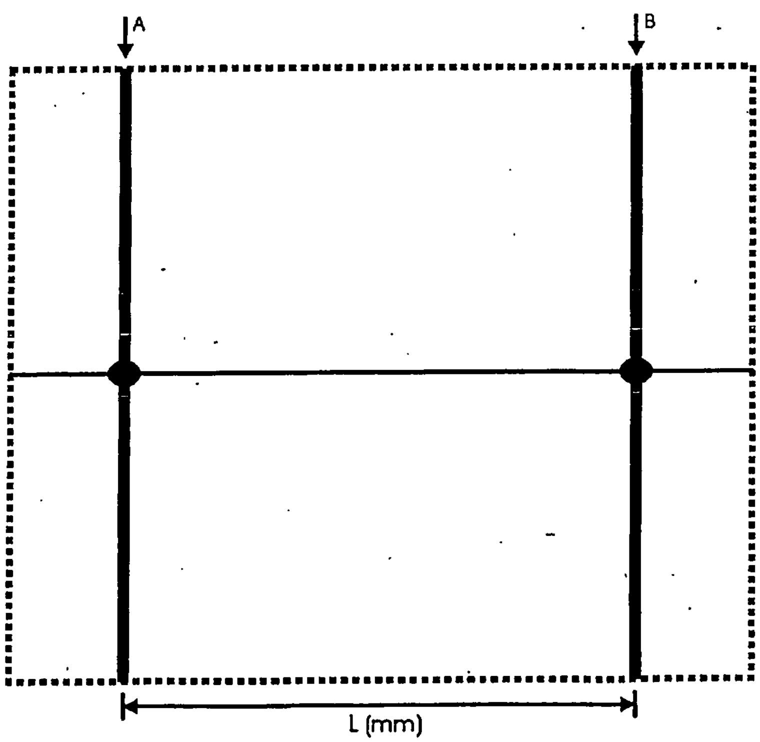


Figure 4. Simple Resistive Element

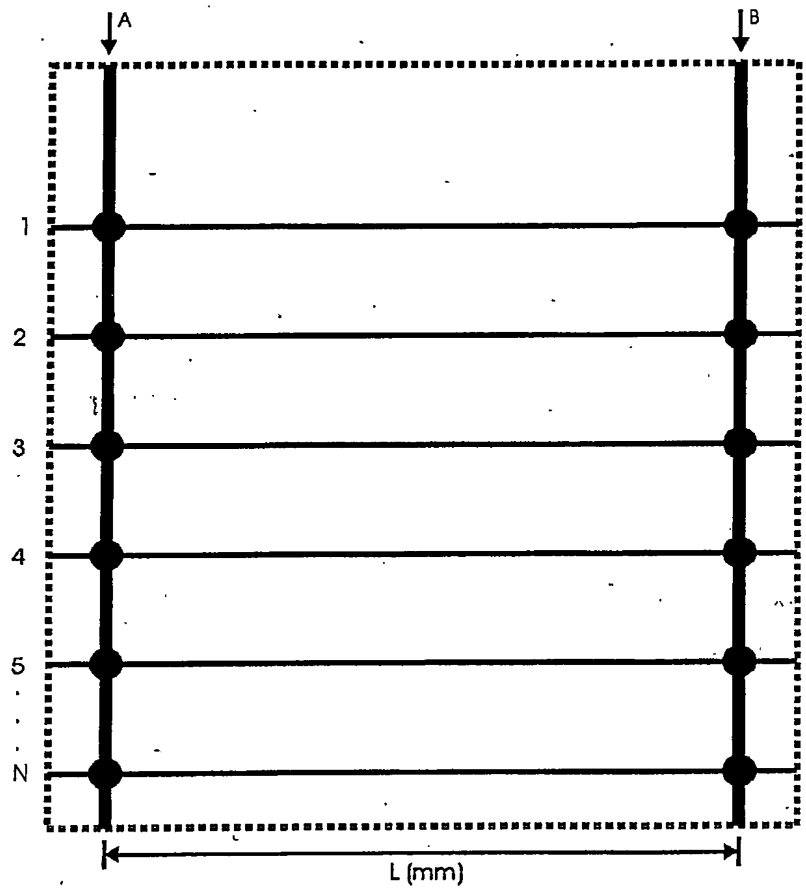


Figure 5. Parallel Resistive Element

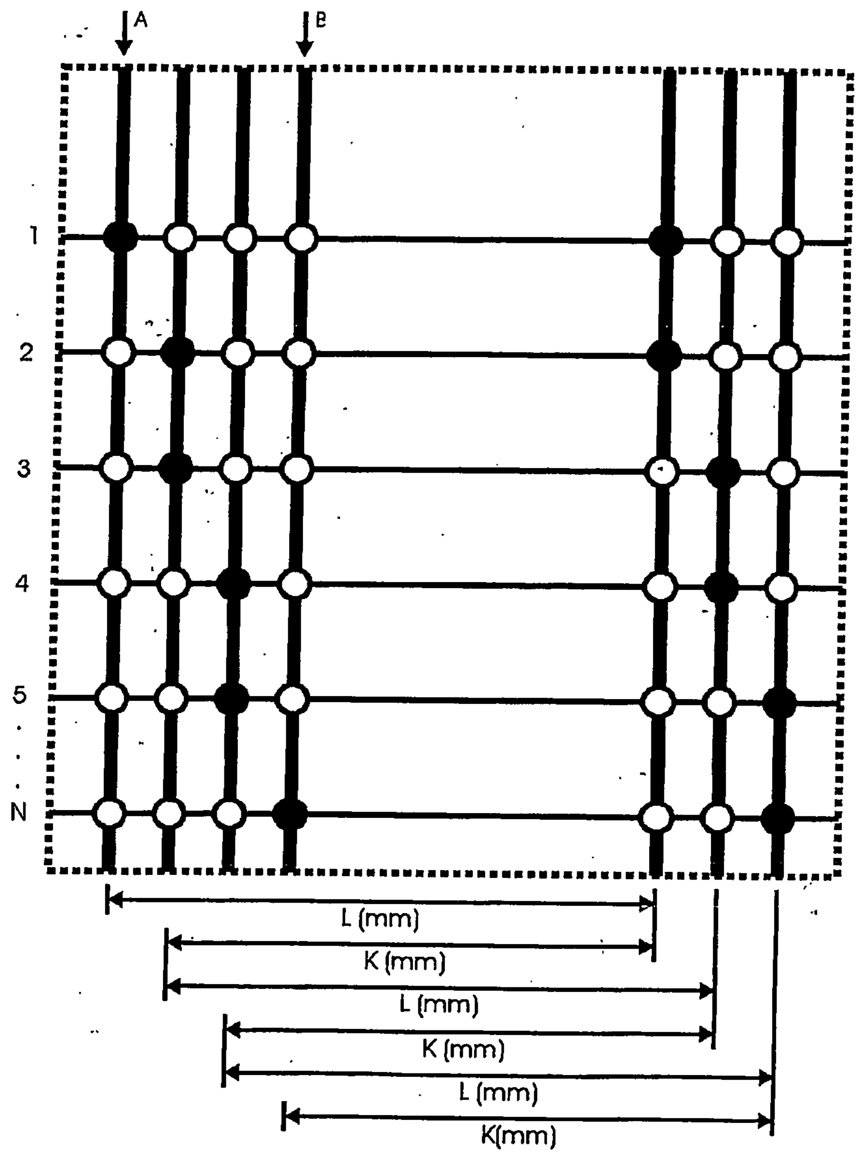


Figure 6. Series Resistive Element with Serpentine Structure

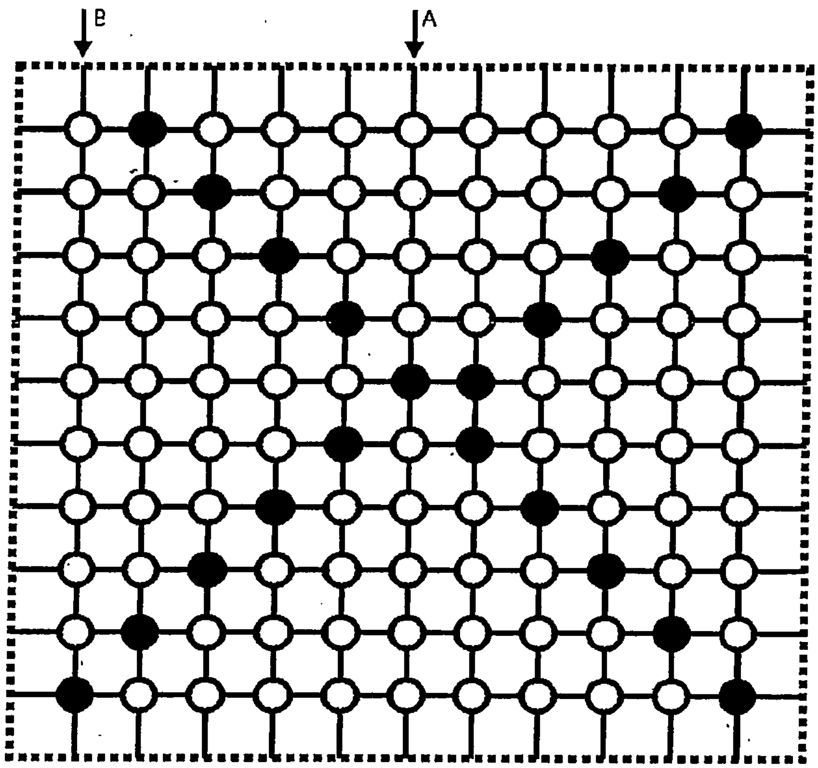


Figure 7. Series Resistive Element with Spiral Structure

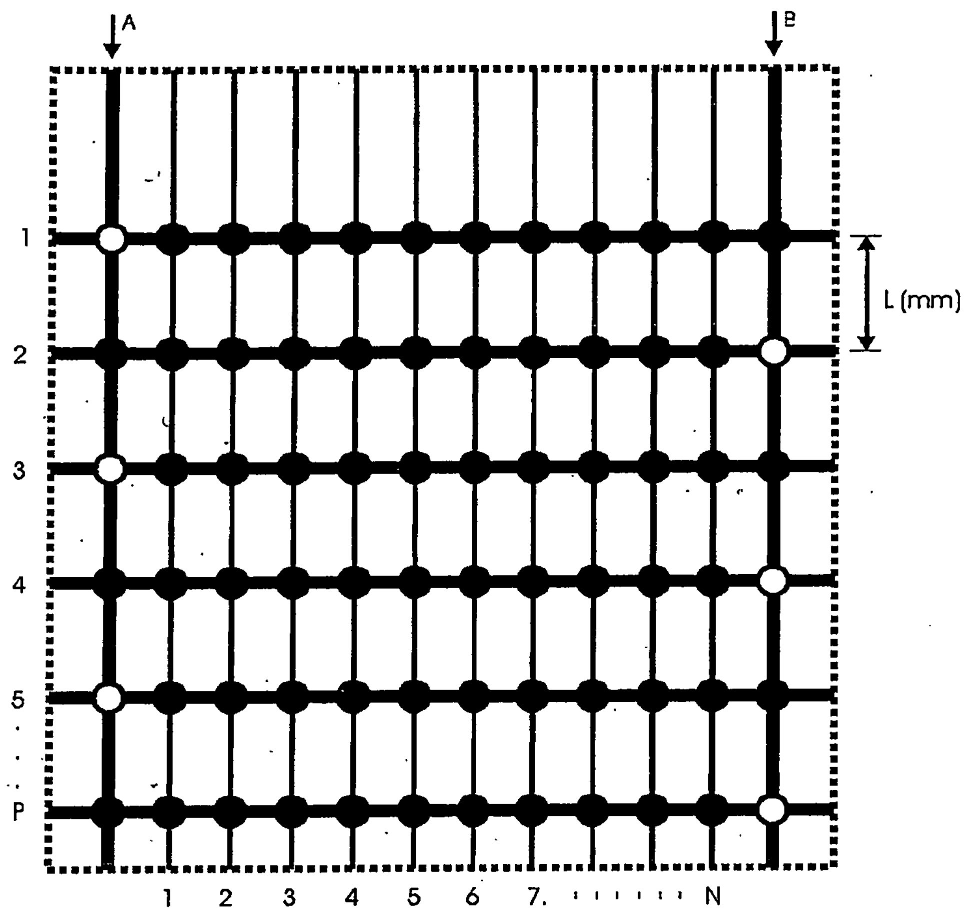


Figure 8. Parallel Interlaced Resistive Element

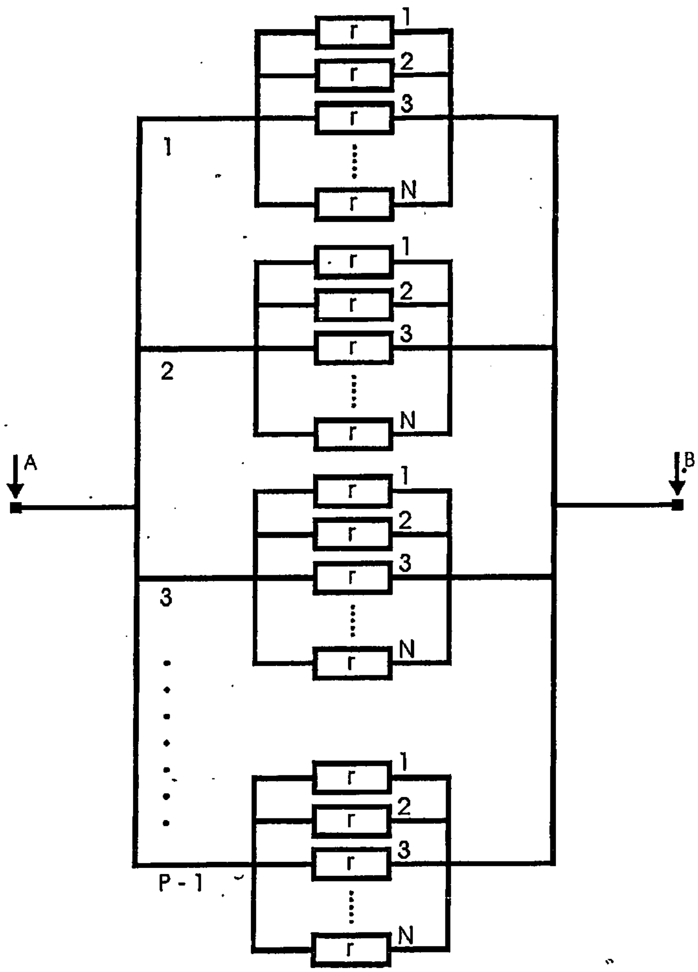


Figure 9. Parallel Interlaced Resistive Element, Equivalent Circuit